# Adaptation of the French rational road design procedure to airfield pavement: the Alize-Airfield software

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ABSTRACT: Alize-Lcpc is the reference software for roads and motorways pavement design in France since more than thirty years. It is a rational method, based on the computation of the resilient stresses and strains in roadways by the classical multi-layer elastic linear model. The design is carried out by comparing these calculated values in all the layers, to the admissible stresses and/or strains values which are evaluated according to the fatigue characteristics of the materials (bounded materials) or their rutting behavior due to plasticization (untreated materials and soils), taking into account the cumulative traffic specified for the pavement. In France, the adaptation of the road design approach to airport pavement is now in progress, leading to the development of a specific version of Alize-Lcpc software dedicated to the design of both flexible and rigid airport pavements. This paper firstly sums up the basis of the French rational pavement approach. It describes the possibilities of the new software, which are illustrated by an example of thickness design for a flexible pavement.

KEY WORDS: Pavement design, airfield pavement, multi-layer elastic model, fatigue behaviour, pavement damage

## 1. INTRODUCTION

The current French design method for airfield pavement is implemented in the DCA software (ITAC, 1999) distributed by the Civil Aviation Technical Center (STAC). It is based on the CBR (California Bearing Ratio) approach initially developed by the US Corps of Engineers for the flexible pavement, and the PCA (Portland Cement Association) method for the rigid pavement. The deficiencies of these two historic methods are widely recognized today. Among other limits, one main deficiency is due to the equivalent thickness concept which underlies the CBR approach. This concept is not appropriate to characterize more and more high-performance materials and to account for the frequent use of cement treated capping layers. Another restriction is the resort to the deflection-based equivalent single load concept, inappropriate for new types of aircraft (6-wheel bogie for the Boeing 777 or complex landing gear for the Airbus 380 consisting of 4- and 6-wheel bogies). In order to improve the design of airfield pavement, the STAC and the French Public Works Research Laboratory (LCPC) have launched at the end of the 90th a research program designed to work out a new method for structural design of airfield pavements. This new design method is mainly based on the application to airfield structures of the French rational design method for roads and highways used since more than thirty years, with the release of the first version of the Alize-LCPC software (Alize-Lcpc, 2001).

Despite its mechanistic nature, the rational pavement design approach has also strong empirical aspects and needs to be calibrated and evaluated by means of experimentations and feedback from real pavement. The AIRBUS full-scale tests on flexible and rigid pavement (LCPC et al, 2002), (Fabre et al, 2003) realized between 1998 and 2003 on the Toulouse-Blagnac airport by AIRBUS in partnership with the LCPC and STAC significantly contributed to the development of a wide experimental data base (Figure 1). These full-scale data were essential for the implementation of the future design method, leading to a new version of the Alize-LCPC software dedicated to the design of airport structures, namely Alize – Airfield pavement.

Figure 1: AIRBUS tests on flexible and rigid pavement - the AIRBUS aircraft simulator

## 2. THE FRENCH RATIONAL DESIGN METHOD FOR ROADS AND HIGHWAYS

For more than thirty years, the French road authorities have developed a rational approach to pavement design, in the interests of achieving a uniform national roads network. This approach is based on normative stages which focus on materials, their manufacturing processes, implementation and control. It is a rational method, based on mechanistic description of the road behaviour and the computation of the resilient stresses and strains generated by the traffic loads in pavement layers. It also necessitates thorough knowledge of the mechanical characteristics of the materials employed, as well as control over their manufacture and implementation. It makes it possible to adjust the thickness of the structure to the local context (bearing capacity of the subgrade and traffic), according to the materials used and the investment/maintenance policy adopted. Today most of the French road owners take advantage of this uniform approach and apply it to the needs of the traffic their own networks have to carry. The process of new pavement design is described in details in the technical guide Design Manual for Pavement Structures (LCPC and al, 1994). The principles and the main entry parameters of the method are summarized below.

### 2.1. The entry parameters of the French design method

The French design method integrates three entry parameters: the subgrade bearing capacity, the pavement materials and the traffic.

#### 2.1.1 The subgrade bearing capacity

The standardization of studies of natural materials and the methods of treatment and implementation undertaken since the 60's have made it possible to gain fairly precise knowledge of the long-term behaviour of pavement foundations. Classification of soils and natural materials and their use in pavement foundation, fill and capping layers are detailed in the technical guide entitled Réalisation des remblais et des couches de forme (LCPC and al, 1992). According to various criteria such as the nature of the soil, its short-and medium-term hydraulic characteristics, its possible treatment techniques, the presence of a capping layer (with or without hydraulic binder) the method provides guidance for the determination of:

- the short-term bearing capacity during pavement construction;
- the long-term subgrade behaviour, in the form of a pavement foundation class (PF1 to PF4). A computation module is attributed to each of these classes (Table 1).

Table 1: Classes of subgrade bearing capacity

| | PF1 | | PF2 | | PF3 | | PF4 |
|---|---|---|---|---|---|---|---|
| Limits of the classes (MPa) | 20 | 50 | | 120 | | 200 | |
| Module for the design (MPa) | 20 | | 50 | | 120 | | 200 |

The pavement foundation class is attributed on the basis of measurements of bearing capacity and/or the deflection carried out in situ, using specific devices as the LCPC-Deflectometer and the LPC-Dynaplaque (LCPC, 2000).

### 2.1.2 Materials

Table 2: Some typical values of material characteristics for the design

| Bituminous materials : (a) standard value at temperature 15°C, Frequency 10 Hz (b) see §2.3 | | | | | |
|---|---|---|---|---|---|
| Material | Young modulus (MPa) (a) | Poisson coefficient | ε6 (µstrain) (b) | -1/b (b) | Kc (b) |
| Asphalt concrete (BBSG) | 5 400 | 0.35 | 100 | 5 | 1.1 |
| Roadbase asphalt concrete (GB3) | 9 300 | 0.35 | 90 | 5 | 1.3 |
| High modulus asphalt concrete (EME2) | 14 000 | 0.35 | 130 | 5 | 1 |
| Materials treated with hydraulic binders (b) see §2.3 | | | | | |
| Material | Young modulus (MPa) | Poisson coefficient | σ6 (MPa) (b) | -1/b (b) | Kc (b) |
| Aggregates and cement mix (GC3) | 23 000 | 0.25 | 0.75 | 15 | 1.4 |
| Aggregates and cement mix (GC4) | 25 000 | 0.25 | 1.20 | 15 | 1.4 |
| Roller-compacted concrete | 28 000 | 0.25 | 1.85 | 15 | 1.50 |
| Cement Concrete | | | | | |
| Cement concrete for slabs and CRCP (BC5) | 35 000 | 0.25 | 2.15 | 16 | 1.5 |
| Lean cement concrete (BC3) | 24 000 | 0.25 | 1.63 | 15 | 1.5 |
| Untreated granular materials (b) see §2.3 (c) maximal value in base course | | | | | |
| Material | Young modulus (MPa) (c) | Poisson coefficient | A low traffic (b) | A mean Traffic (b) | |
| UGM category 1 | 600 | 0.35 | 16 000 | 12 000 | |
| UGM category 1 | 400 | 0.35 | 16 000 | / | |
| UGM category 1 | 200 | 0.35 | 16 000 | / | |

The mechanical performances necessary for road construction materials either treated with bituminous binders or with hydraulic binders are characterized by laboratory tests.

- tests on bituminous materials in order to determine their ability to compaction and, when required, their resistance to rutting, their resilient modulus and their resistance to fatigue;
- tests on cement treated materials in order to determine their resilient modulus and their resistance to direct or indirect traction, also used for the determination of their fatigue performances according to empirical correlations.

Fatigue curves are expressed in terms of strain for bituminous materials, and stress for concrete and materials treated with hydraulic binders. Untreated materials have mechanical characteristics which are a function of their mode of production and of the characteristics of the aggregates. For the structural analysis, in the absence of any specific study on the material considered, standard values for the Young modulus and standard fatigue characteristics are used (Table 2).

### 2.1.3 Traffic

In the French design method, the cumulative traffic over the service life of the pavement is converted into an equivalent number of passes of a reference axle, which causes the same structural damage to the roadway as the actual composite traffic. The French reference axle is a single axle with dual wheels of 130 kN (3.25 kN per wheel). Thus, the cumulated number of heavy lorries (NPL) intending to drive on the roadway is multiplied by a mean coefficient of traffic aggressiveness (CAM) to obtain an equivalent number of passes (NE) of the reference axle: NE = NPL x CAM

The main coefficients of aggressiveness result from statistical studies taking into account the traffic survey on road and highway. They depend on the mean daily traffic flow, the wheel and axle lorry configurations and the nature and thickness of the pavement material.

## 2.2. Thickness design for new roadways

The design of a new pavement begins with the choice of the type of surfacing to be employed. The experience and the application of value analysis to pavement lead to design structures by drawing a distinction between the functions fulfilled by the surfacing and those fulfilled by the structural underlying layers. The choice of surfacing composition is carried out according to local experience and to the objectives pursued with respect to the intended use characteristics of the roadway, as friction, noise, comfort in rainy weather, smoothness of ride according to the service level of the road, etc.

On the opposite, the choice of materials and thicknesses for the structural layers is carried out according to a mechanistic approach. First, the materials are selected and the thicknesses are computed with regard to their mechanical resistance beyond the expected traffic. Then it has to be checked that the structure will be able to withstand the frost period without damage. The design in terms of mechanical resistance consists in checking that the pavement structure is sufficient to respond to the constraints imposed by the traffic cumulated over the whole specified service life. This verification is carried out by comparing:

- the maximal stresses and/or strains created in the different pavement materials by the reference load, which are calculated using the multi-layer linear elastic model (Burmister's model) implemented in the Alize-LCPC software,
- and the allowable stresses and/or strains for each material, which are derived from the fatigue characteristics resulting from laboratory tests (treated materials) or empirical failure relationships (untreated materials and soils).

The structure is appropriate if the first stress and/or strain values computed by the model are less than or equal to the second one depending on the fatigue or failure criteria of the considered material. The damage due to repeated loading is assumed to be caused by fatigue in the treated materials and permanent deformation in untreated layers and subgrade. Therefore the relevant failure criteria are:

- tensile strains due to bending deformation at the base of the bituminous layers,
- tensile stresses due to bending deformation at the base of materials treated with hydraulic binders and concrete,
- vertical compressive strains at the top of not treated materials and subgrade.

2.3. Allowable stress and strain values

The allowable value represents the maximum level of stress or strain, applied as many times as the number of traffic load passes, that the material is able to withstand before being subjected to a given level of damage. This level of admissible damage is specified by the road owner, according to the level of service expected for the pavement and is expressed as the risk of failure of the pavement over the whole service life. The effect of the risk parameter on the allowable value is based on a probabilistic approach, which is an original feature of the French design method. It takes into account the scattering of the fatigue mechanism in treated material observed both in laboratory and in situ, combined with the dispersion of the layer thicknesses in real pavement.

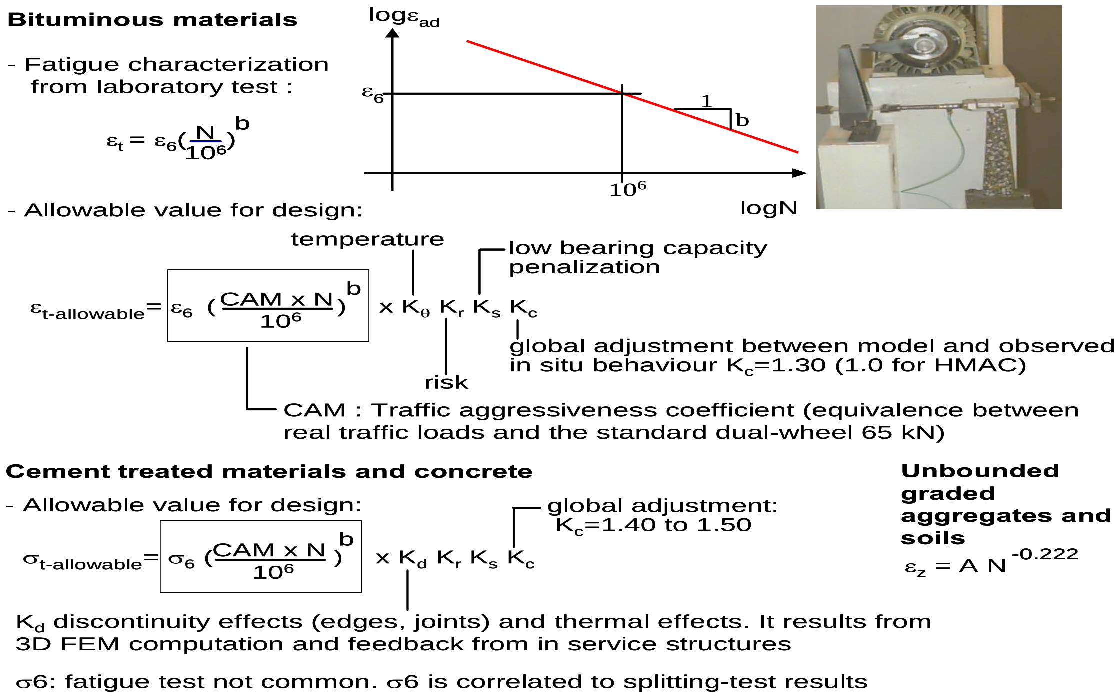



Figure 2 : General expression of the allowable strain and stress value

In the case of bituminous materials, materials treated with hydraulic binders and concrete, the allowable stress or strain value at the base of the layer is thus a function of (Figure 2):

- the fatigue behaviour of the material expressed by parameters ε6 (or σ6) and b which are the characteristics of the fatigue curve obtained in the laboratory;
- the cumulated equivalent traffic NE = CAM x N over the service life of the pavement;
- the subgrade bearing capacity level soil, through a penalization of the allowable value for low bearing capacity: Ks = 1/1.2 for PF1 and 1/1.1 for PF2 subgrade, and Ks = 1 for PF3 and PF4;
- the risk of rupture, as explained above, which is a parameter specified by the road owner reflecting his road strategy;
- the effects of discontinuities encountered in rigid structures (slab joints, edges, cracks in CRCP (Continuously Reinforced Concrete Pavement), combined with the curling-warping thermal gradient. They are taken into account through the Kd coefficient (1/1.70 for un-dowelled slabs and 1/1.47 for dowelled slabs and CRCP), which results from three-dimensional FEM (Finite Element Model) computations performed on some French typical rigid structures under typical thermal conditions;

– the experimental adjustment of the design model (coefficient Kc) by means of feedback derived from the observation of real pavement behaviour and damage mechanism, and from full scale tests performed with the LCPC Accelerated Pavement Testing facility (LCPC, 2001)

In the case of untreated materials and soils, the failure criterion represents the rutting damage due to excessive permanent strains. It does not take into account any risk parameter and the criteria parameter (cf. Figure 2, coefficient A) depends neither on the mechanical performance level nor on the bearing capacity of the considered material.

## 2.4. Equivalent temperature of AC materials

It should be observed that the fatigue parameter $\varepsilon_6$ of bituminous materials depends on temperature and frequency. However, in practice, $\varepsilon_6$ is determined at 10 °C and 25 Hz only. Then, for pavement design calculations, two assumptions are made:

– the influence of frequency on ε6 is neglected (ie. design calculations are performed at 10 Hz);
– and the variation of ε6 with temperature is assumed to verify the following simplified relationship, for any temperature θ:

$$\varepsilon_6\,(\theta).(E(\theta))^{0,5} = \varepsilon_6\,(15°C).(E(15°C))^{0,5} = \text{constant}$$

where E(θ) is the complex modulus. This relationship is a simplification, and its validity is presently the subject of experimental research performed by LCPC.

As taking into account temperature variations in design of bituminous pavements is difficult and requires local statistical data generally unavailable, design is performed, in France, for a single temperature, called the equivalent temperature $\theta_{eq}$. $\theta_{eq}$ is defined as the single temperature leading to the same damage of the pavement as the real temperature variations. The calculation of $\theta_{eq}$ requires knowing the variation of modulus and fatigue properties of bituminous materials with temperature. If such results are generally available for the modulus, it is seldom the case for fatigue properties, so that the previous simplified relationship between θ and E is generally used. For the French climatic condition, the so defined equivalent temperature varies in the range about 13°C-18°C. In common practice, a constant equivalent temperature of 15 °C is assumed for design of bituminous pavement.

# 3. EXTENSION OF THE RATIONAL METHOD TO THE DESIGN OF AIRFIELD PAVEMENTS

The French rational pavement design method for roads and highways presented above has been extended to the design of airfield pavements, leading to a specific version of the Alize software dedicated to airport structures, namely the Alize-Airfield pavement software. This new version of Alize software has been developed by the LCPC under a cooperative agreement with the STAC. In the near future, the Alize-Airfield pavement software is expected to replace the existing official CBR and PCA design methods for airport structures. As the other versions, Alize-Airfield pavement software runs on Personal Computer under the latest Microsoft operating systems. The Alize-Airfield pavement program consists of two main data entry sections.

3.1 The Structure data section

It consists of the Structure window (Figure 3) allowing the selection of the structure under evaluation. The thicknesses of the different layers must have been pre-estimated by the user. The material properties of pavement layers and subgrade are characterized in terms of elastic modulus, Poisson's and type of layer interface (bonded, half-bonded and unbonded). Modulus values must be selected for compatibility with French standards and recommendations.

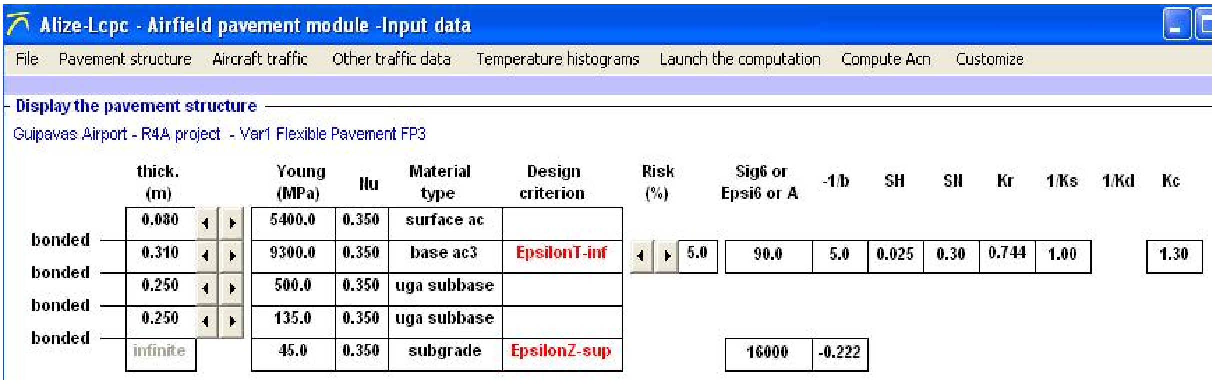



Figure 3: Alize-Airfield Pavement – the pavement window, including the structure layers and materials characteristics - Example

The failure criteria for the design are also defined in this first window. They are basically the maximum allowable vertical compressive strain at the top of subgrade and the maximum allowable tensile strain at the bottom of asphalt layers for flexible design, and the maximum tensile stress at the bottom of concrete slabs and cement treated materials for rigid and semi-rigid structures. As for the road design, the determination of allowable values considers an adjustment coefficient (Kc) aimed to correct the laboratory approach by taking into account the real behaviour and damage process observed on actual pavement. Besides the allowable value computation also considers the risk of pavement failure specified for the pavement, according to a probabilistic approach taking into account the uncertainties in material property assumptions. For example a design failure risk of 5% means that it is specified that not more than 5% of overall length of the pavement will present structural failure, necessitating structural reinforcement or rebuilding, at the end of the design life.

3.2 The Aircraft traffic mix section

It consists of two windows allowing the creation and modification of aircraft traffic to be taken into account for the design (Figure 4). The airplanes are selected from a library involving 250 aircrafts, including the most recent ones (A380-800, A380-800AF, A340-600 and B777-300ER). The whole geometry of the aircraft is featured at scale and in interactive mode, with an ability to get information about the gear geometry: radius, weights and contact pressures of all the wheels and their distances to the nose gear, longitudinal paths of the wheels. All the information about the manufactured aircraft is stored internally as part of the library and cannot be changed by the user. However, a specific gear configuration may be introduced if needed.

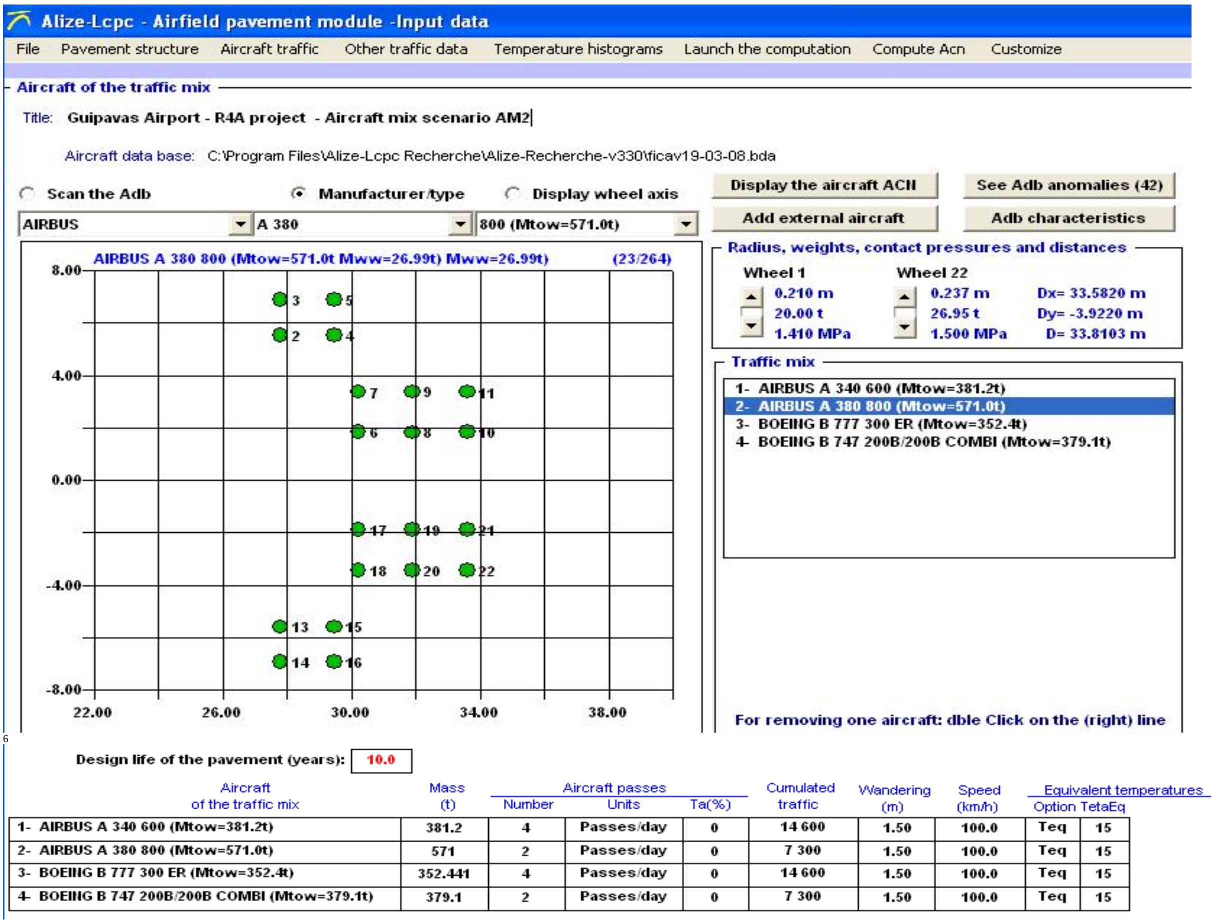



Figure 4: Alize-Airfield Pavement – the Aircraft traffic window, including landing gears geometries, weights, number of passes and equivalent temperature in AC materials - Example

The following data for each aircraft of the traffic mix have to be defined: gross load, number of aircraft passes, annual traffic increase rate, and lateral wandering. The lateral distribution of traffic is taken into account by combining the individual damages created by the aircraft at different transversal distance from a given computation point, using the Miner's rule. On the contrary it should be mentioned that in the conventional design procedure (DCA software), the statistics of aircraft wander are accounted for in terms of a pass-to-coverage ratio fixed at 3.65, with the assumption that the aircraft wander depends neither on the aircraft nor on pavement structure and materials. The moving speed of the aircraft and the equivalent temperature in bituminous materials have also to be given as defined by the French design guide for road pavement – LCPC 1994, possibly different from one aircraft to another. These two parameters allowing to take into account the thermo-viscoelastic behaviour of these materials are used for the determination of the Young modulus of each bituminous material in the multi-layer elastic model.

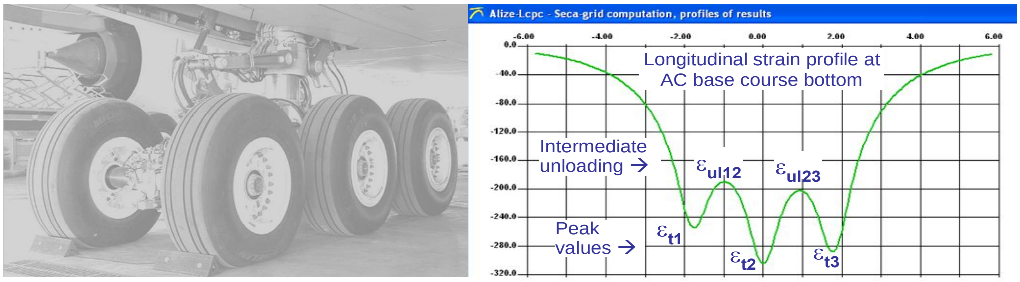
### 3.3 Other features of Alize-LCPC software

The failure criterion is not limited to the single subgrade damage due to permanent deformation, as it is supposed by the current CBR design method for flexible pavment. A second failure criterion is also considered, namely the fatigue cracking of asphalt layers. Due to the thermo-viscoelastic of bituminous materials, the modulus of asphalt materials depends on solicitation frequency and temperature. Standard frequency for current road pavement

design is conventionally set at 10Hz (for moving speeds around 100km/h). In the Alize Airfield pavement software, the frequency is automatically computed according to the airplane speed, considering the pseudo-frequency of the strain signal created at the base of bituminous materials by a reference single wheel. In the same way, the standard temperature of 15°C, usually considered for the French road thickness design, is a priori not suitable for airfield pavement. The equivalent temperatures for each failure criteria may be automatically calculated for each aircraft included in the traffic mix, according to a statistical histogram representative of the distribution of the aircraft traffic versus the mean temperature in asphalt material over the whole service life of the pavement. The computation of equivalent temperature is performed by elementary computations of the damage due to a reference load for each temperature class, and by using the cumulative damage Miner's law.
It has to be underlined that this way of taking into account the thermo-viscoelastic behaviour is indeed very approximate, and inappropriate to precisely reproduce the physical behaviour of bituminous materials. For that purpose, more accurate numerical tools for modelling the thermo-viscoelastic behaviour of bituminous materials in pavement problems have been developed by LCPC, namely the Cesar-LCPC – modulus CVCR finite element model (Heck, 2001) and the ViscoRoute software (Duhamel and al, 2005), which follows a quasi-analytical procedure. Although they are quite promising, this new approach of bituminous pavement response is not yet fully operational for current design, and it is still reserved to research and expert studies.

### 3.4 Damage computation and results

Instead of computing the strain and stress values at a pre-assumed locations (CBR-based methods), the Alize software computation are done at discrete points defined inside a 2D uniform horizontal grid whose discretization can be customized (10 cm by default). This 2D computation grid is automatically adapted to each considered airplane. The results in terms of strains and/or stresses are presented as longitudinal or transversal profiles or as 2D or 3D surface isovalues. The stress or strain longitudinal profiles are used in order to compute the damage due to each aircraft along the profile transversal to the runway, using the Miner's cumulative damage law.
In the case of multi-axle loading (4 wheels and 6 wheels bogies), the cumulated damage in classical pavement design application is usually computed only considering the maximal tensile values at the peaks corresponding to each axle (discretized Miner's law). The feedback from real pavement and fatigue studies in laboratory (Bodin et al, 2009) lead to think that the effect of multi-axle loads cannot be reduced to such a simple summation of the peak damages, but has to take into account the entire stress or strain temporal response signal. Experimental and theoretical research aiming at improving the effects of multipeak strain path on the fatigue performances of bituminous materials is presently carried out by LCPC. A first version of such a complete cumulated damage law is implemented in the Alize-LCPC Airfield pavement software. It consists in a continuous integration of the original elementary damage accumulation Miner's principle. This complete integration along the longitudinal profile take into account not only the maximal tensile strain values at peaks, but also the strain unloading between each peak, as illustrated by figure 5. In comparison to the discretized Miner's law at peaks, the complete integral damage accumulation law generally leads to reduce the damage due to multi-axles bogie, which is more conformable to real behaviour and damage process observed on real pavement.




Damage law (treated, untreated materials and soils) : $s_{rev} = K N^b$
with $s_{rev}$= resilient stress or strain

Elementary damage (Miner) : $\delta D = \frac{1}{N} = [\frac{s_{rev}}{K}]^{\alpha}$ with $\alpha = -1/b$

Integral formulation of the Miner law (continuous integration the along moving load axis) :

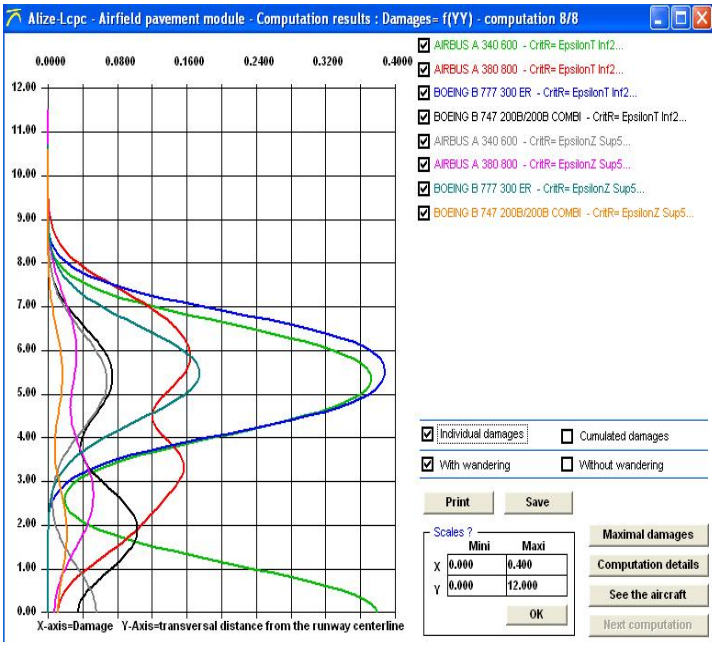
$$\delta D = \frac{\alpha}{K^{\alpha}} \int_{-\infty}^{+\infty} s_{rev}^{\alpha-1} \, pos[\frac{ds_{rev}(x)}{dx}] \, dx \qquad \text{with } pos(X) = \left| \begin{array}{l} X \text{ if } X>0 \\ \text{else: } X=0 \end{array} \right.$$

Example: Tridem cumulated damage (cf. longitudinal strain profile):

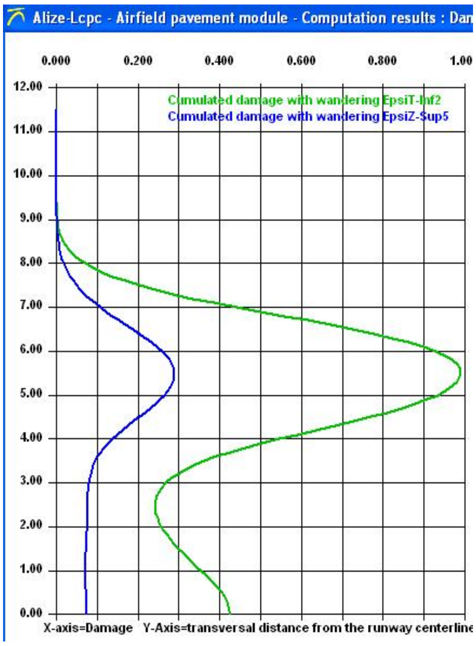
$$d_{tridem} = K\,[\varepsilon_{t1}^{-1/b} + \varepsilon_{t2}^{-1/b} - \varepsilon_{ul12}^{-1/b} + \varepsilon_{t3}^{-1/b} - \varepsilon_{ul23}^{-1/b}]$$

Figure 5: Damage computation for multi-axles according to Miner's continuous integration

For each aircraft of the traffic mix, the software provides a plot of the computed damage as a function of the transversal distance to the runway centreline. Four displays are possible: individual damages created by each aircraft of the traffic mix towards each specified failure criteria without and with lateral wandering, cumulated damages regarding each specified criteria with or without wandering (cf. example figure 6).




Individual damages due to each aircraft of the traffic mix, relative to AC base layer fatigue and subgrade failure




Cumulated damage relative to AC base layer fatigue and subgrade failure

Figure 6: Computation results, example for bituminous pavement

The thickness design is based on the assumption that failure occurs when the cumulated damages for each design level is equal to 1 (100%). Cumulated damages greater than 1 do not necessarily mean that the pavement will no longer support traffic, but that it will have failed according to the definition of the probabilistic failure defined above. Bearing in mind all the assumptions and definitions on which the design procedure is based, thicknesses adjustments – and other materials choices if needed - should be made manually so that the cumulated damage is as close as possible to 100% in the final design.

For the example presented in figure 6 (using the input data presented above) the dominant criterion for design is the tensile strain at the bottom of the base asphalt layer, which failure is is predicted to anticipate the subgrade failure. The Boeing B777-300ER is the most damaging aircraft, with regards to the AC failure criterion as the subgrade ones. It accounts for 38% of the cumulated damage of AC and 17% of the subgrade**.** Regarding the AC failure, the Airbus A340-600 (tow 381t) is very close to the B777-300ER (tow 352t) with a damage factor of 37%. Although the A3800-800 (tow 571t) is significantly heavier than the three other airplanes, its damage effect is remarkably moderate in comparison with the B777-300ER and the A340-600, with damage factors of 16% and 5% for AC and subgrade failure respectively.

## 4. CONCLUSION

The Alize Airfield pavement software is not yet fully operational for design application, is still undergoing refinement with a necessary calibration phase (mainly a complete determination of the Kc coefficient for the different materials) and a subsequent global validation phase, expected to be completed before the end of 2009. By this time, the French official procedure for the design of airfield pavement (DCA software) will be replaced by the new rational method. The authors are aware of the limitations of the isotropic linear elastic theory which underlies this new rational design approach. But they believe it already affords considerable benefit, when compared to the CBR or PCA-based method. The Alize Airfield pavement software should be viewed as a first step towards a more comprehensive model not operational so far for design applications (neither for road and highway nor for airfield pavement design).Compared to the existing design software, the Alize program is intended to optimize the design procedure, by reducing the extent of excavation work and the volume of unbound graded aggregates and by optimizing the thickness of the structural layers.

Finally, it should be pointed out that a detailed comparison between the Alize-Airfield pavement software and the Faarfield software developed by the FAA is presented in a companion paper published in the present 2010 FAA Technology Transfer Conference proceedings (Brill et al, 2010). This second paper describes the specifics of each of the two programs, contains a sensitivity study about the influence of various input parameters, and a comparison of the design thicknesses obtained by the French and US approaches.

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